UC Berkeley Boston Colorado Draper Georgia State
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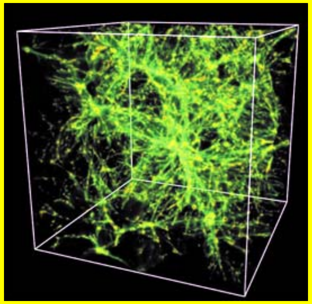
Spectroscopy and Photometry of the IGM's Diffuse Radiation (SPIDR): A NASA Small Explorer Mission

SMEX Kick-off Meeting

"GSFC" August 20, 2002

spidr

The Mission: Mapping the Missing Baryons



Primary Science

SPIDR will detect, map, and quantify an enormous volume of the Cosmic Web of Warm-Hot ($10^5 – 10^7$ K) Intergalactic Medium (WHIM). The WHIM is thought to contain as much as 50% of the baryons in the local universe.

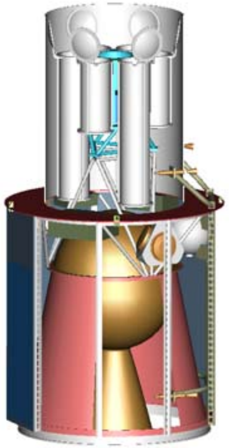
Major Characteristics

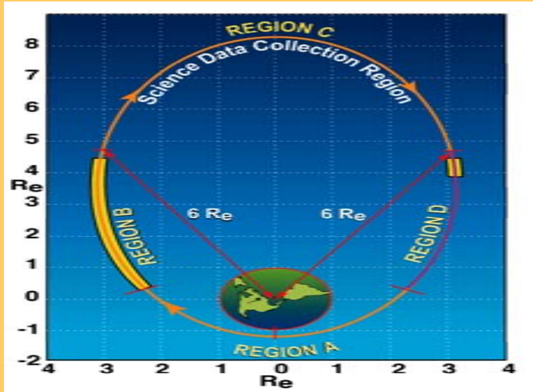
- 25% sky coverage
- Simultaneous imaging and spectroscopy over (8° × 8°) field
- 3 instruments consisting of 6 independent spectrographs
- SPIDR's MDF requirement for OVI is ~2000PU (2′ × 2′)
- 4-color UV fluxes to 18th mag
- Fully funded science program
- Fully-funded GI program
- 3-year mission
- No consumables

Simple, lightweight, high-sensitivity spectrographs

Engineering unit built in Phase A

Simple spacecraft having components with extensive heritage





High Earth Orbit (HEO) to minimize geocoronal Ly α background and maximize observing efficiency

People

The Science Team

Mark Bautz	MIT
Claude Canizares	MIT
Renyue Cen	Princeton U.
Supriya Chakrabarti (PI)	Boston U.
Timothy Cook	Boston U.
Nahide Craig	UC Berkeley
Alexander Dalgarno	Harvard / CfA
Carl Heiles	UC Berkeley
Edward Jenkins	Princeton U.
Jon Lapington	Boston U.
H. Richard Miller	Georgia State
Jeremiah Ostriker	Princeton U.
Kenneth Sembach	STScI
J. Michael Shull	CU, Boulder
Adolph Witt	U. Toledo

Other Key participants

J. Swider	BU
R. Goeke	MIT
B. Klatt	MIT
S. Smith	Draper
M. Matranga	Draper
S. Battel	*Battel Eng.*
D. Bradford	BU
P. Vedder	*Genl. Dyn.*

SPIDR Science Objectives

- Detect and map diffuse O VI and C IV emission to determine the amount and distribution of collisionally ionized gas at temperatures $T = 10^5$-10^6 K. This will be the first opportunity to image a phase of the ISM/IGM that so far has been detected only by absorption spectroscopy toward point background sources.
  - within the Cosmic Web at low redshifts
  - in the Magellanic Clouds and local galaxies
  - within the Galactic disk and halo
  - within Galactic supernova remnants and loops
- H_2 fluorescence and starlight scattered by dust
- Emissions from planets, comets
- Objectives defined by Guest Investigators

The Inventory of Baryons at Different Epochs

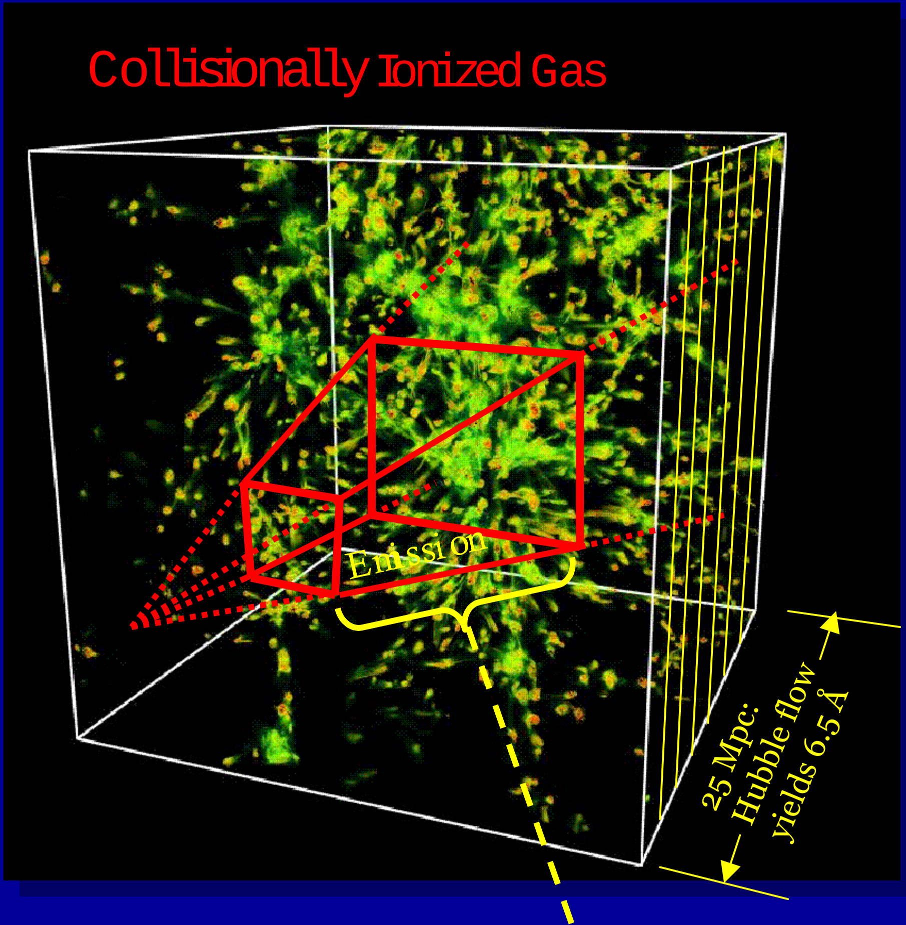
- The Earliest Beginnings ($z \approx 1000$ - 10^{10})
  - CMB Struct. & primordial D/H $\longrightarrow$ $\Omega_b = 0.037$ (total)
- The Distant Universe ($z \approx 3$)
  - **Cool (10^4 K) intergalactic gas:** $\Omega_b > 0.030$ **(>81%)**
- The Nearby Universe ($z \approx 0$)
  - **Cool (10^4 K) intergalactic gas:** $\Omega_b = 0.008$ **(~21%)**
  - **Hot gas in galaxy clusters:** $\Omega_b = 0.002$ **(~ 5%)**
  - **Ordinary stars in galaxies:** $\Omega_b = 0.003$ **(~8%)**
  - **Very cold gas in galaxies:** $\Omega_b = 0.0006$ **(~ 2%)**
- SUM of observations: $\Omega_b = 0.014$ (~38%)
- *Where's the remaining ~62% ?*

"Warm-Hot" Intergalactic Medium and its Distribution

- For the temperature regime $T = 10^{5.3} - 10^{6}$ K, O VI is the best tracer of this medium and feedback processes.
  - Absorption
  - Emission
- Hotter gases are sensed by x-ray line emission and absorption

Sampling O VI in the Universe

- Spectroscopy and Imaging of emission lines arising from collisional excitations
  - allows <u>complete</u> coverage of a volume of space
  - most sensitive to the densest regions
  - spectral resolution avoids confusion arising from projection



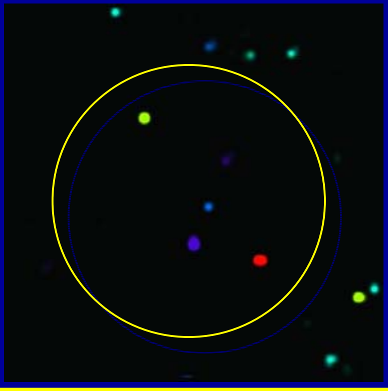
$$\int \rho_m n_e F(T) \mathrm{dl}$$

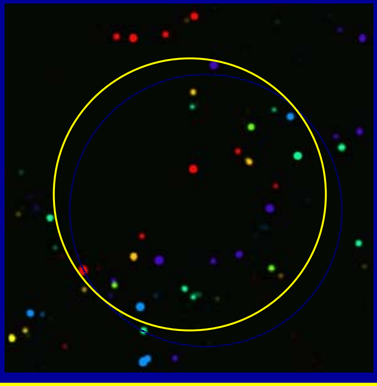
Selected Samples of O VI Emission in a Single Observation of 1 week duration

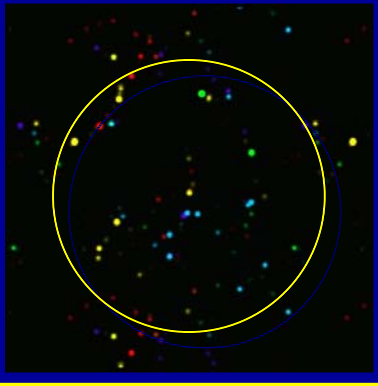
Colors indicate relative redshifts within each range

Redshift *z* → 0.017 – 0.023 | 0.063 – 0.068 | 0.143 – 0.147

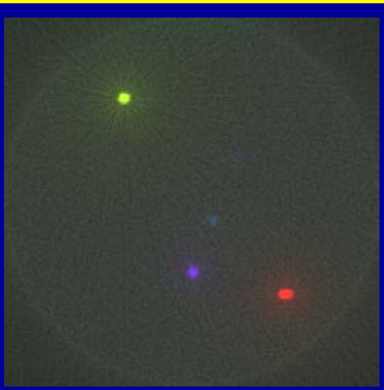
Distribution of O VI emitting gas from a cosmological simulation, used as input for the data analysis

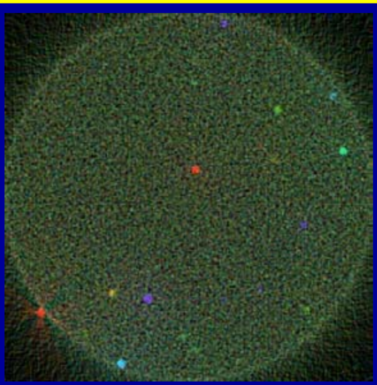


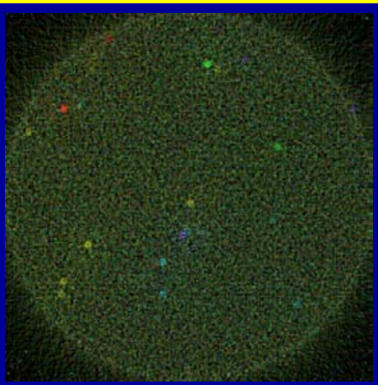




Output from the data analysis, with appropriate noise amplitudes added







Questions

- Are 30-50% of the baryons *really* in the Warm-Hot intergalactic gas?
- Are the metals in situ *really* as high as in the cosmological models?
- Do either supernova wind feedback or cooling flows substantially alter this picture?
- What types of more advanced missions will be needed to refine the conclusions derived from the pathfinding results of SPIDR?

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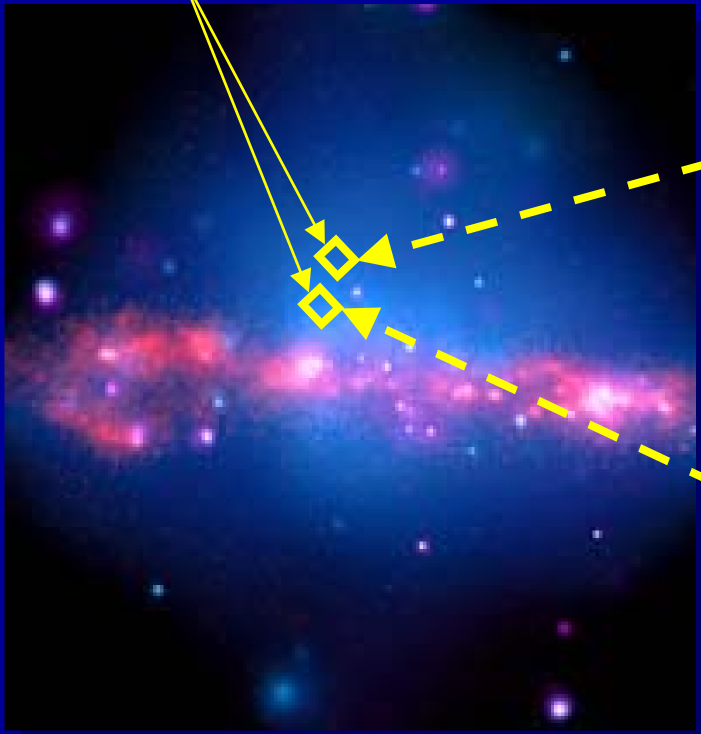
Galactic Halos

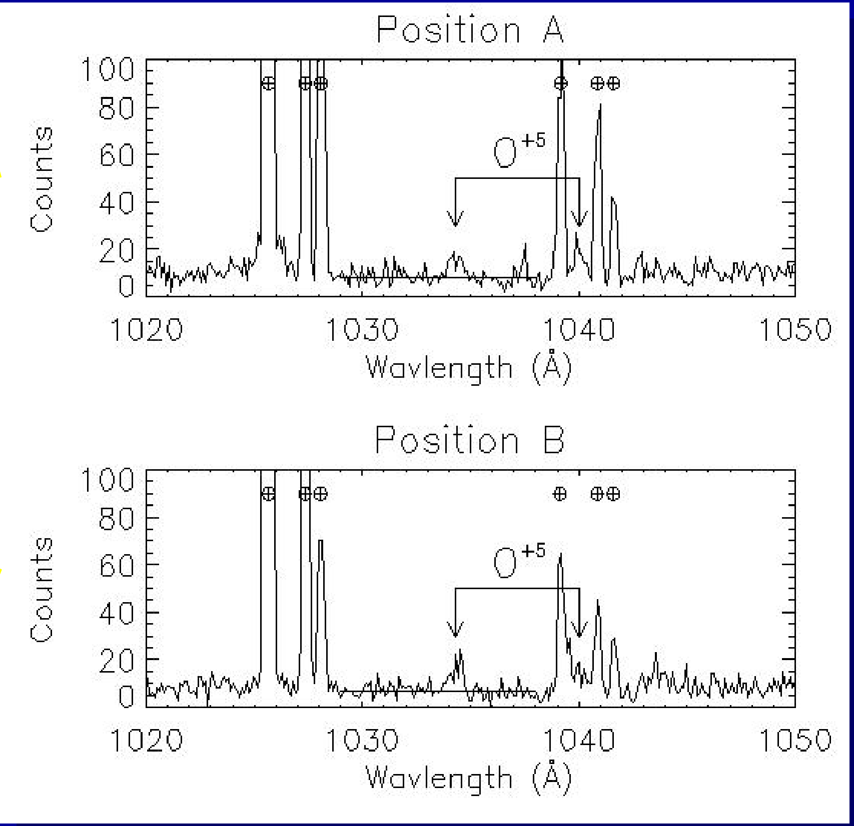
30 arc-sec square apertures – no imaging!



NGC 4631

red: uv from hot stars

blue: x-rays from hot halo



FUSE observations of O VI emission

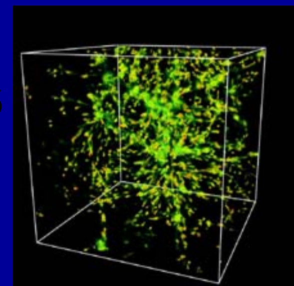
Position A: 4400±1000 PU

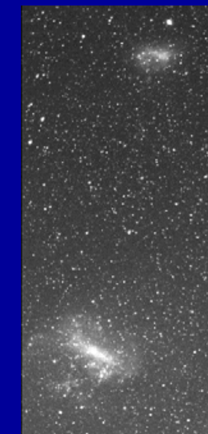
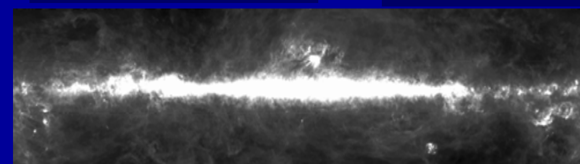
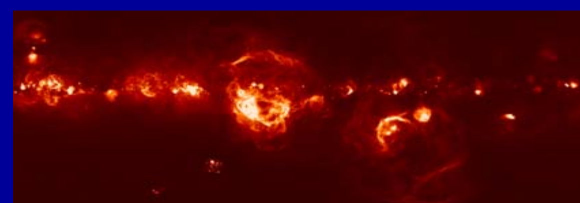
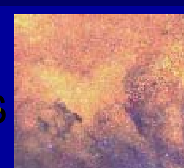
Position B: 7900±1300 PU

Breakdown of Observations

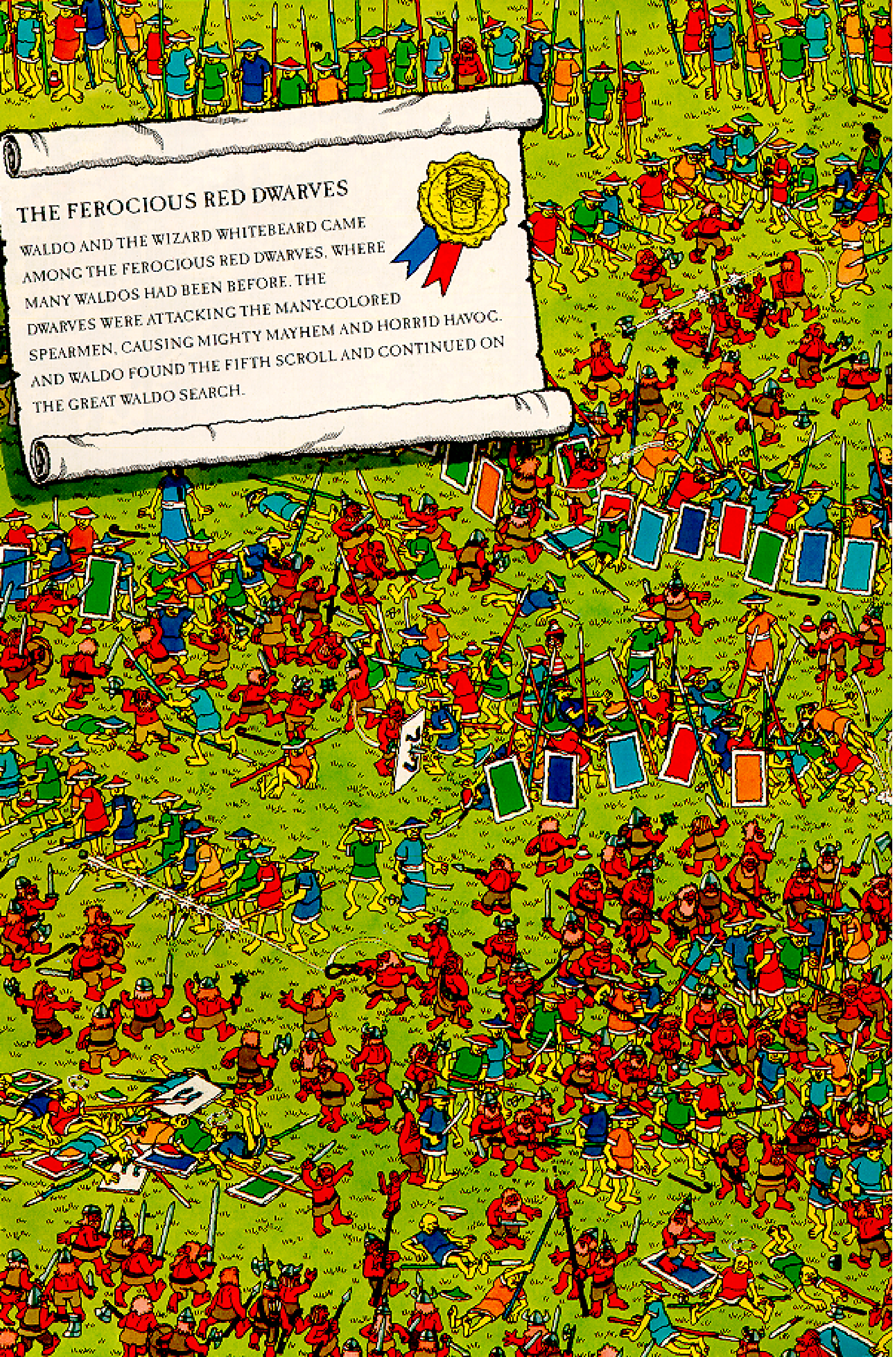
(Numbers indicate weeks of observing time)

- Large Scale Structure and Feedback from galactic winds
  - 50 General baryon search
  - 15 Deep field, single pointing
  - 20 Galaxies & clusters
  - 5 SMC + LMC
  - 10 Magellanic Stream + High Velocity Clouds
- Galactic
  - 20 Supernova Remnants
  - 10 Nebulae, H_2 fluorescence
- Guest Investigator Pgms. (20)
  - May include PNe, cloud shadows in the Local Bubble, Planets, Comets …
- 6 weeks Contingency + Calibrations



156 weeks TOTAL over a 3 year mission

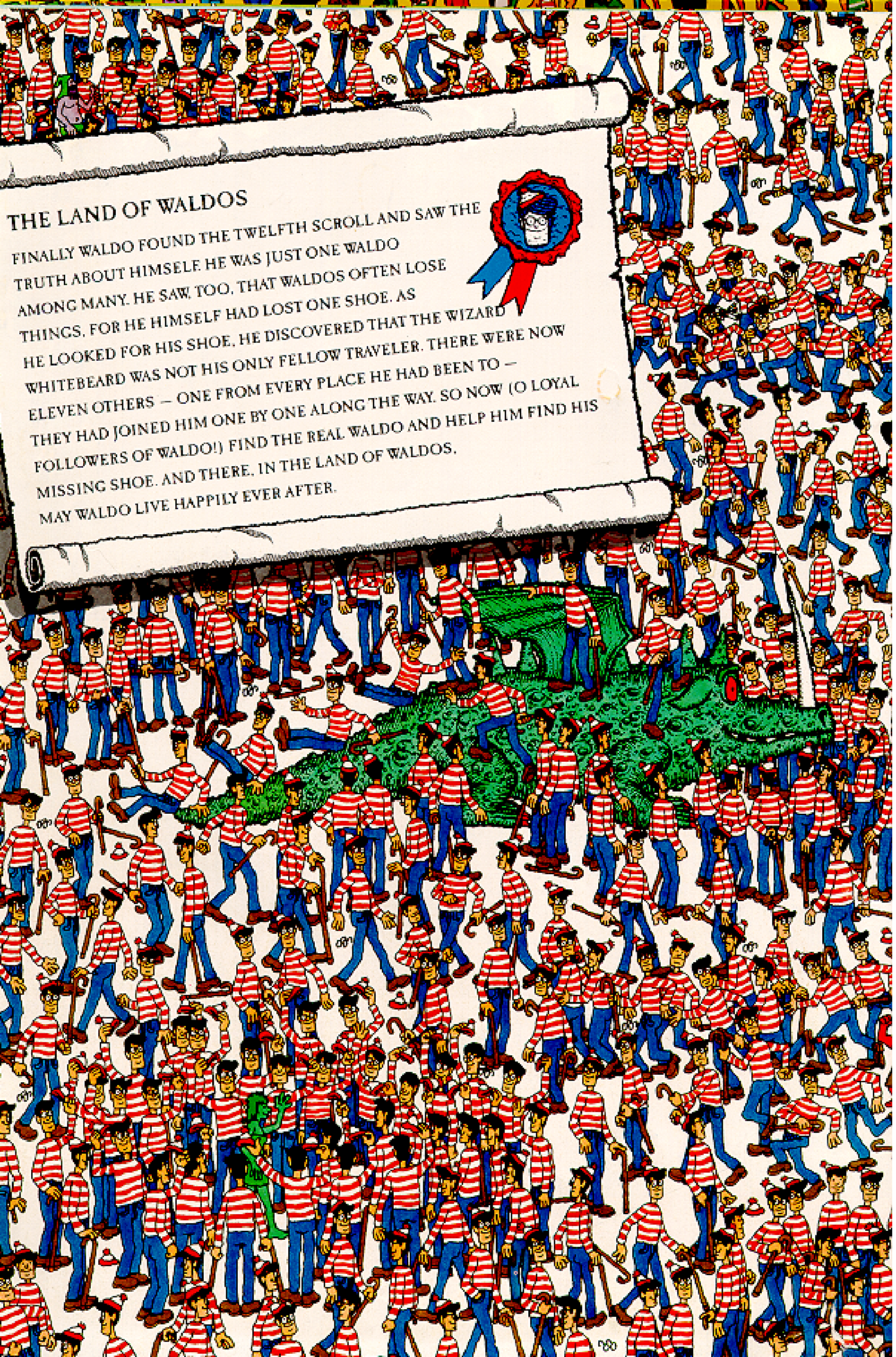


Technique

Observe spectral features that traces $10^5 – 10^7$ K plasma

At Low angular resolution point sources (e.g., stars and external galaxies) appear similar to extended sources

Separate star light from diffuse emissions



Complications

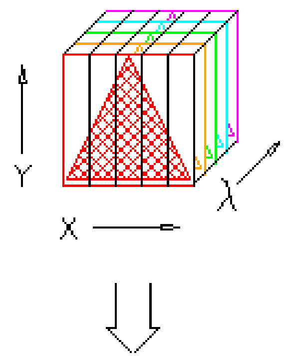
At low spectral resolution, Galactic signal cannot be distinguished from extragalactic signal

Separate Galactic signal from extragalactic emissions

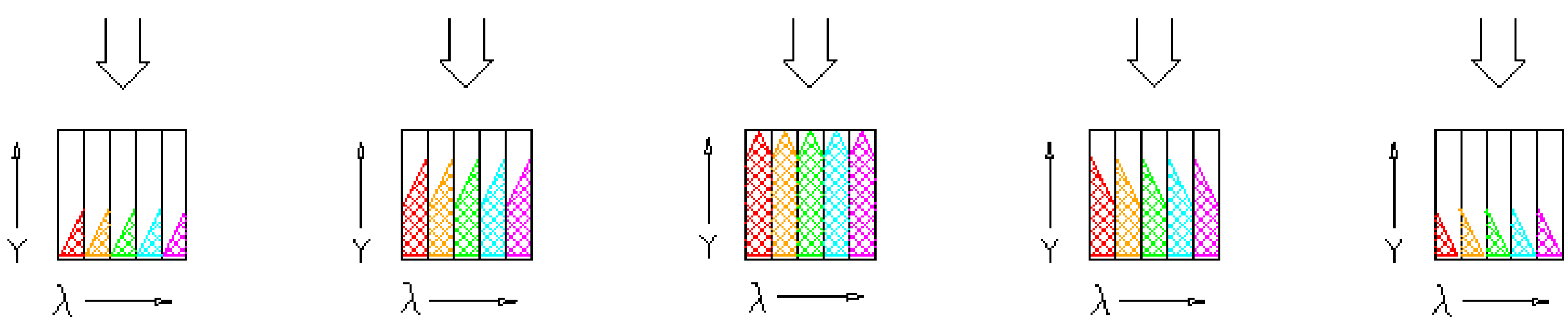
High resolution spectral imaging

Conventional (push-broom) technique

The scene



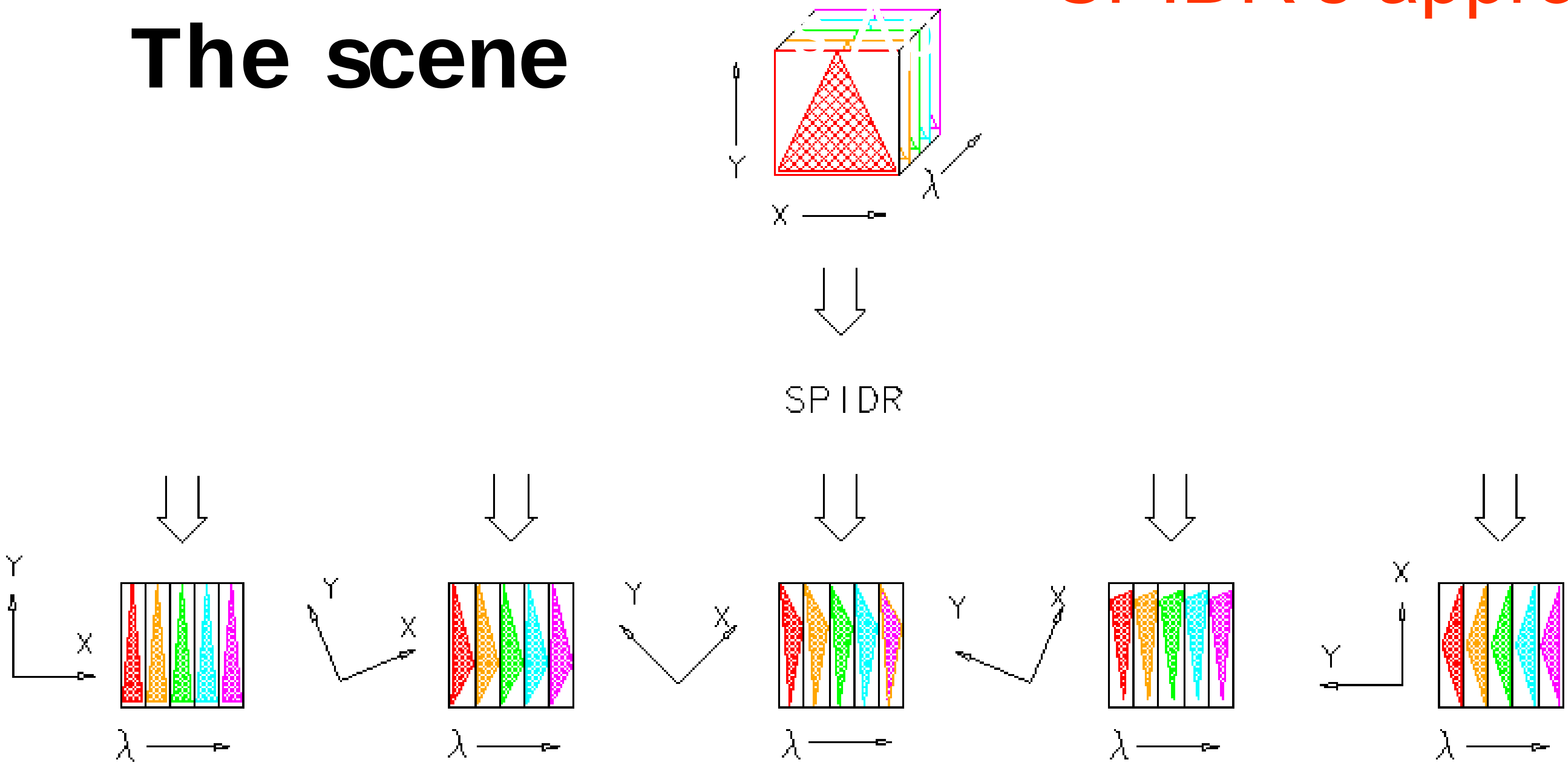
Push Broom Spectrometer



Sampling Technique: Each box represent the detector content at a time step

SPIDR's approach

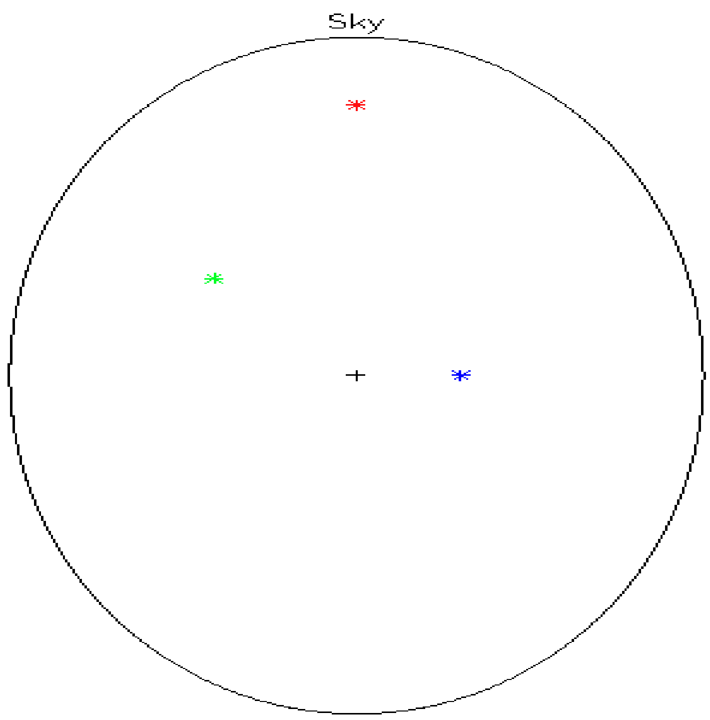
The scene

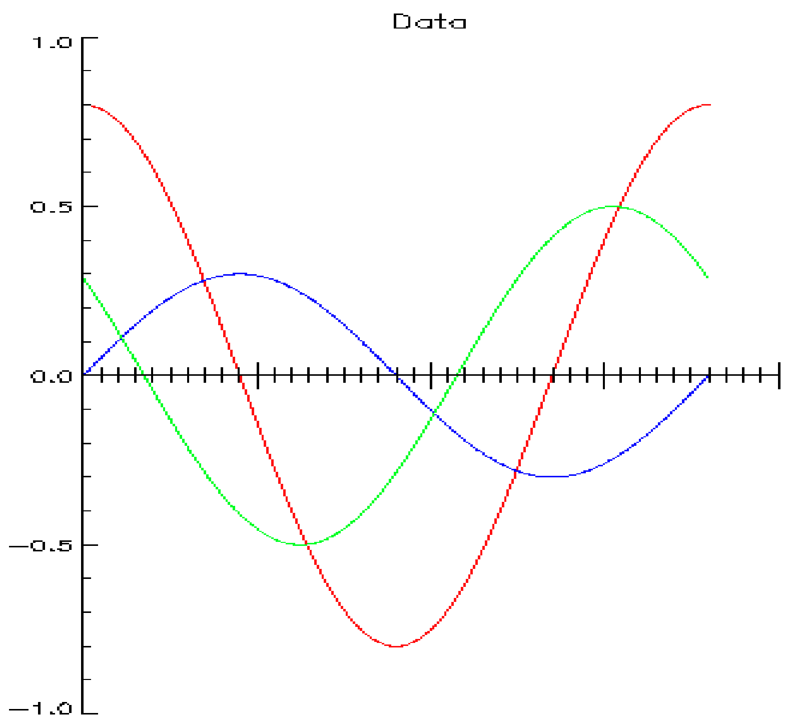


Sampling Technique: Each box represent the detector content at a time step

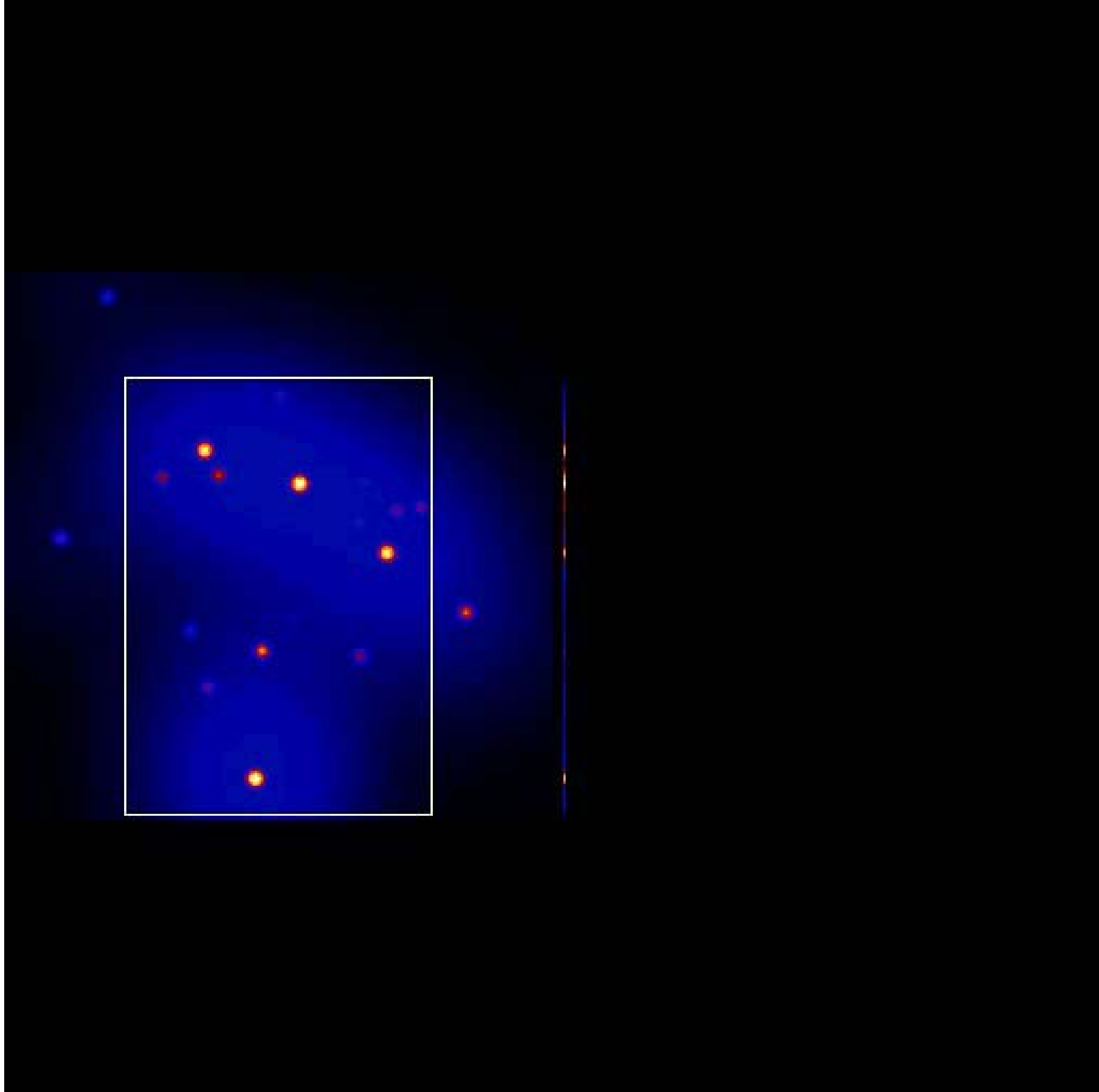
Did you catch the arrows showing the axes?

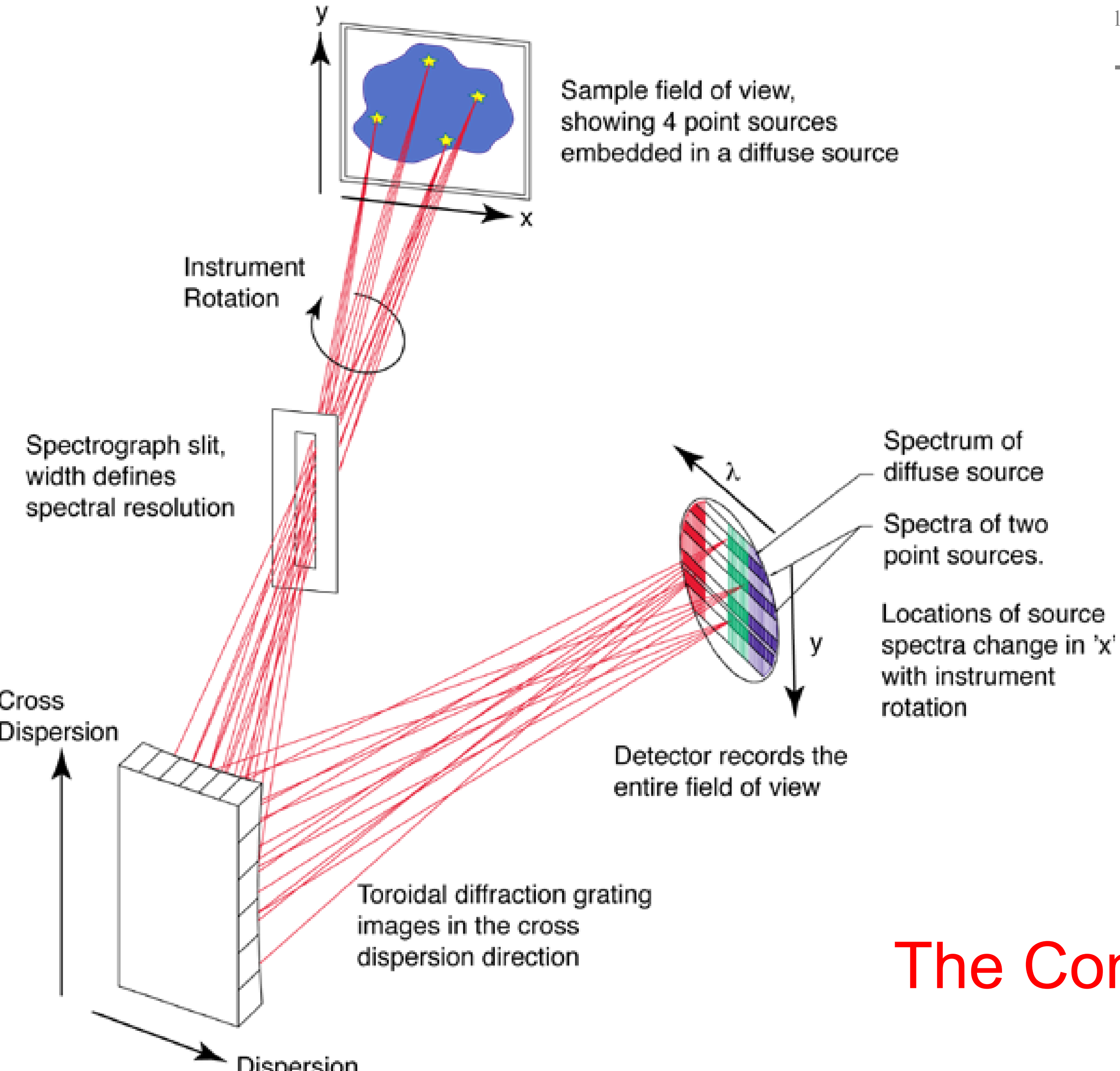
The sky as seen on SPIDR's detector





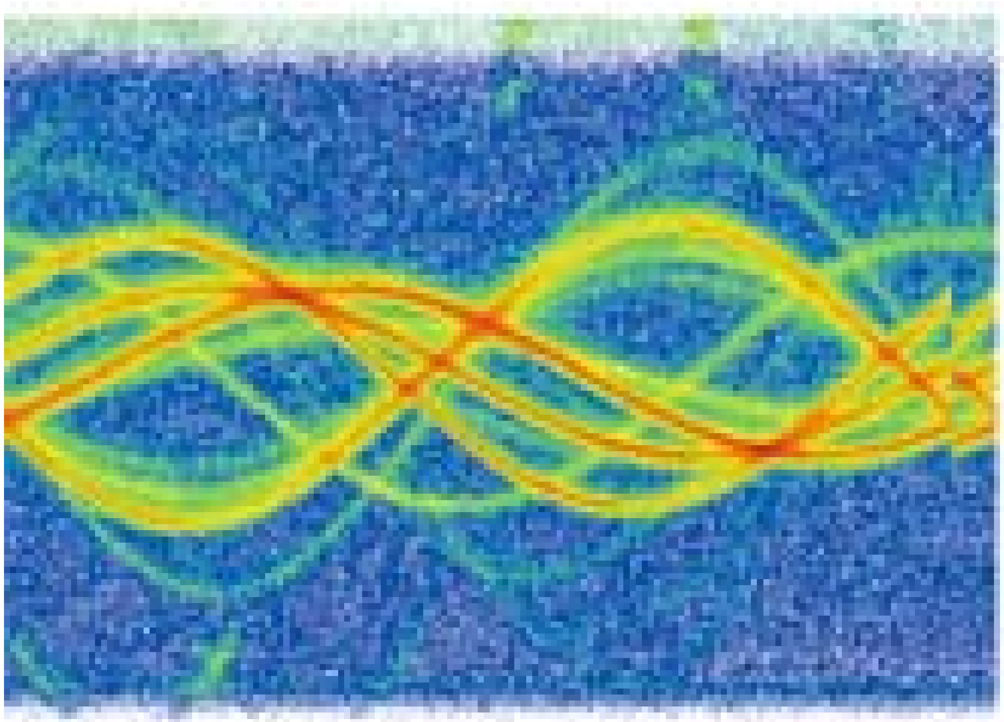
spidr

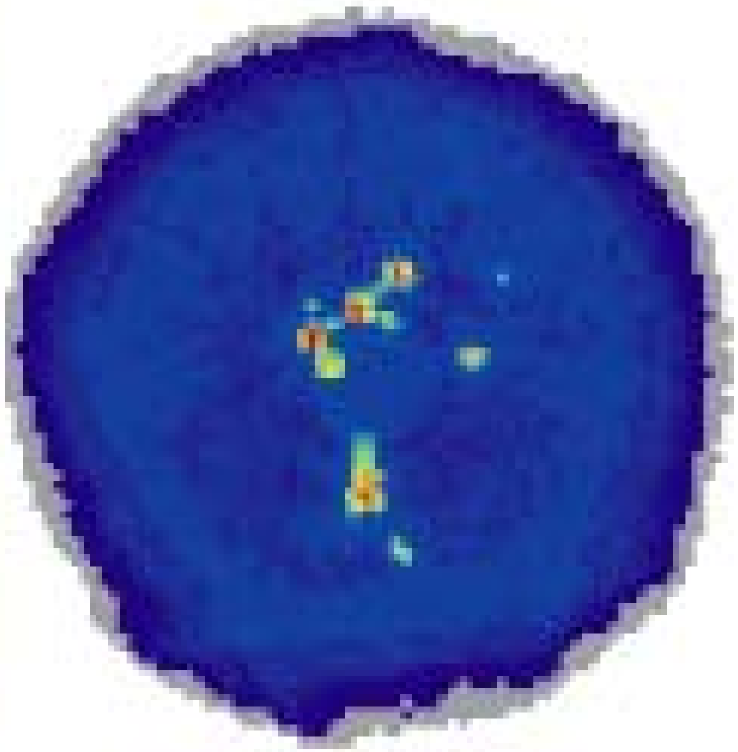



y
x
Sample field of view,
showing 4 point sources
embedded in a diffuse source
Instrument
Rotation
Spectrograph slit,
width defines
spectral resolution
λ
Spectrum of
diffuse source
Spectra of two
point sources.
y
Locations of source
spectra change in 'x'
with instrument
rotation
Cross
Dispersion
Detector records the
entire field of view
Toroidal diffraction grating
images in the cross
dispersion direction
Dispersion

The Concept

Proof of Concept

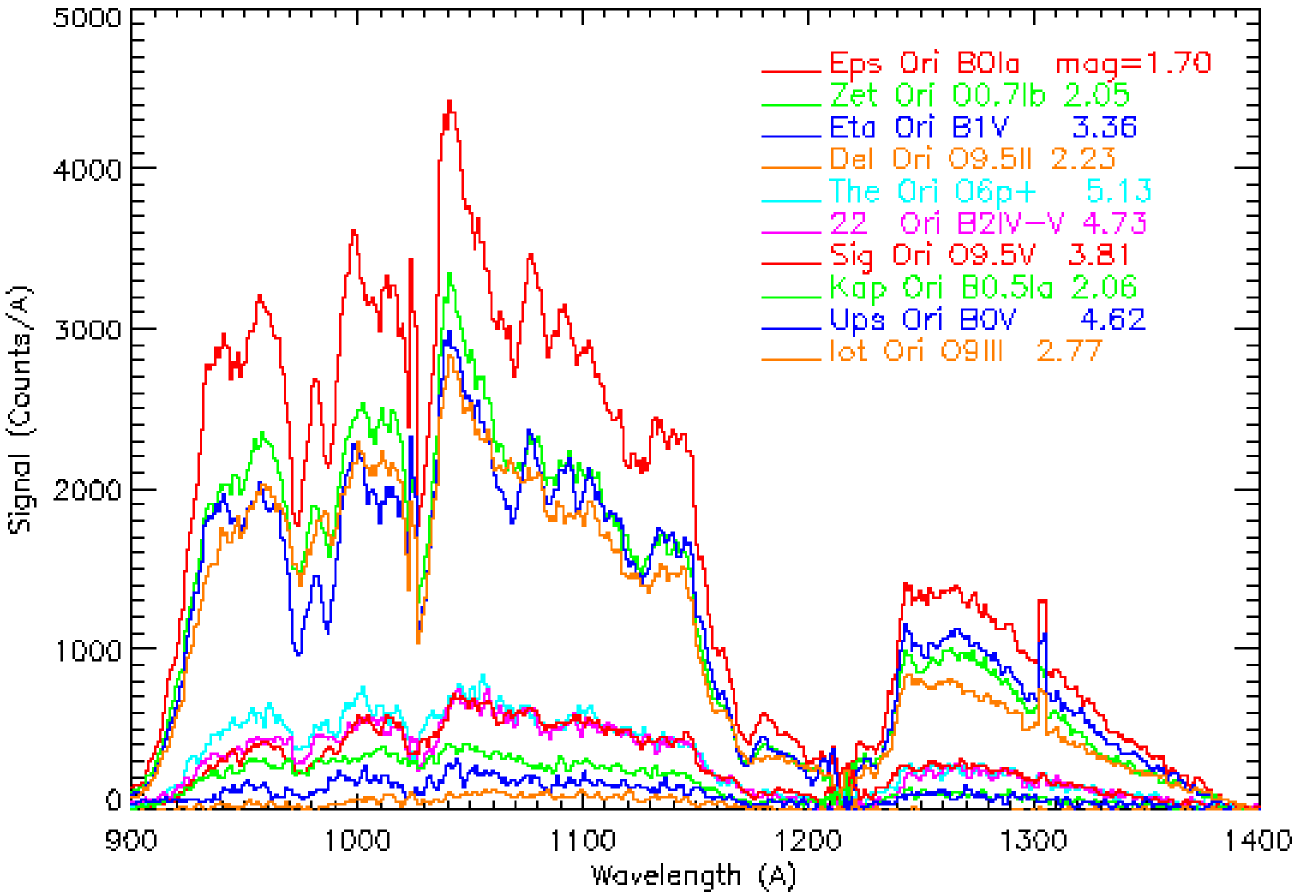




This is real data!

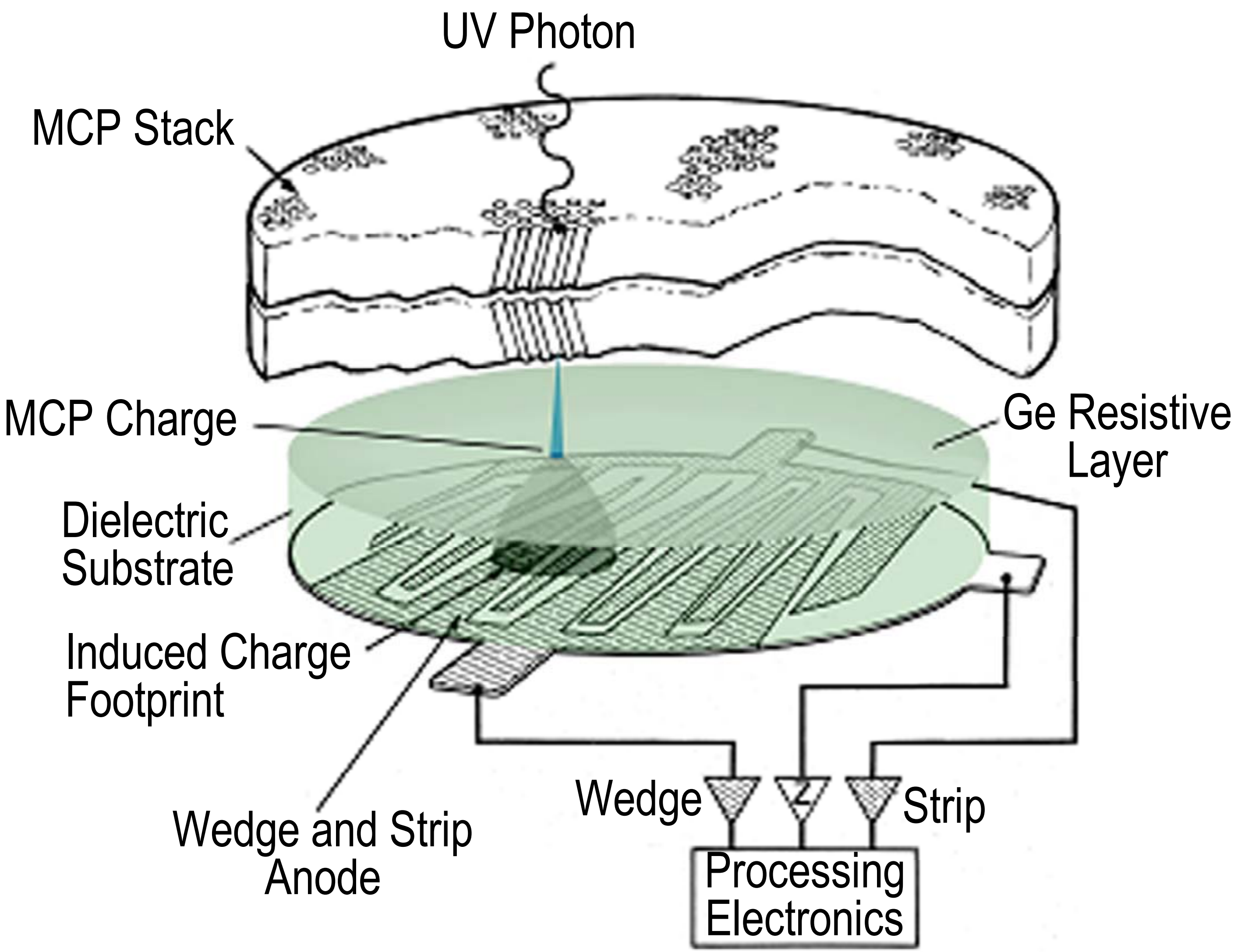
This is the reconstructed image

Multi-object Spectroscopy demonstrated

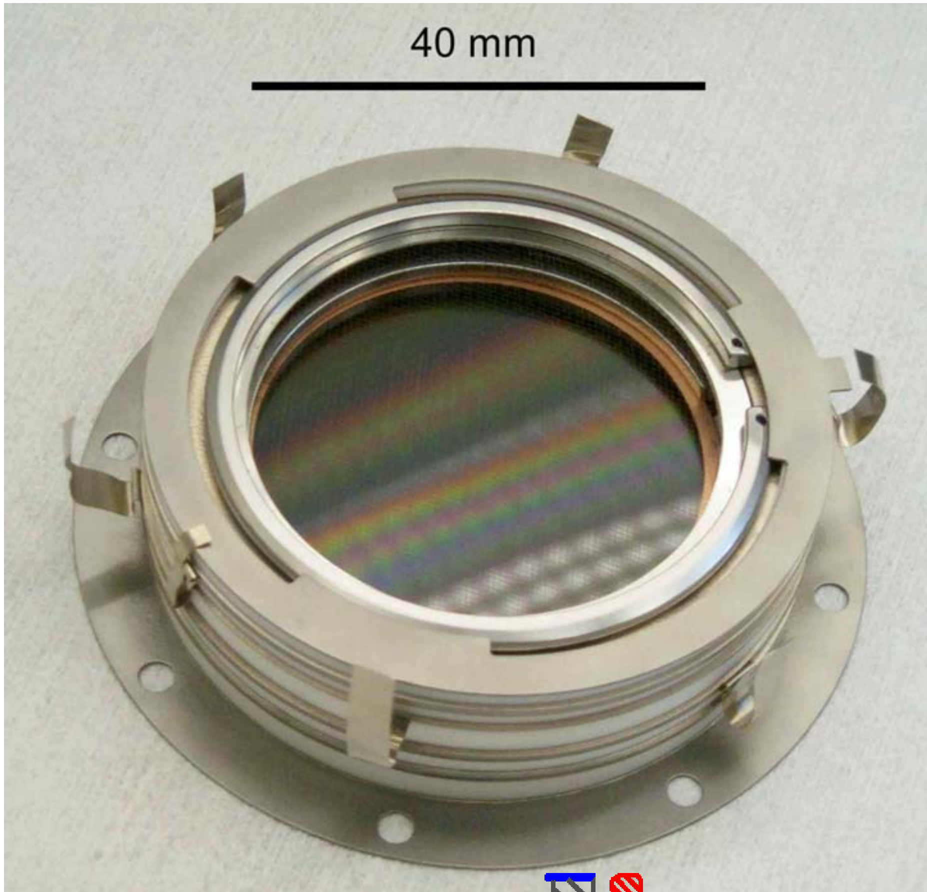


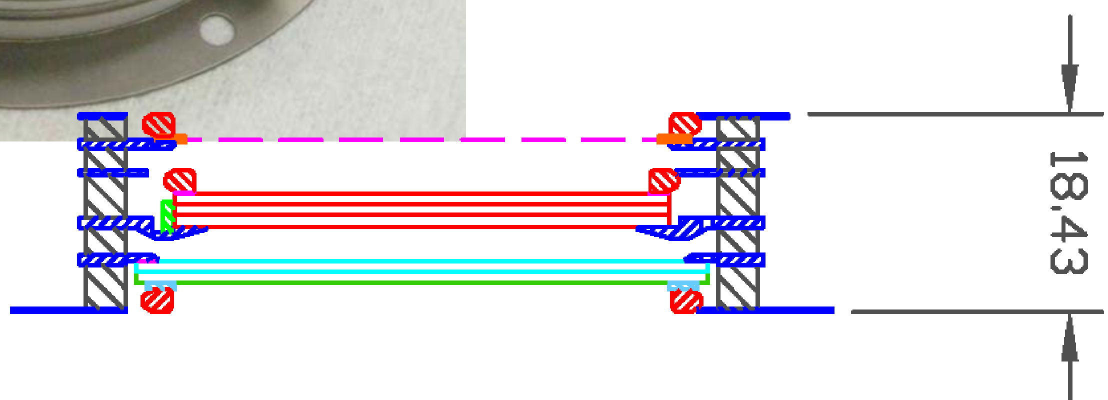
SPIDR Prototype Instrument

SPIDR Detector

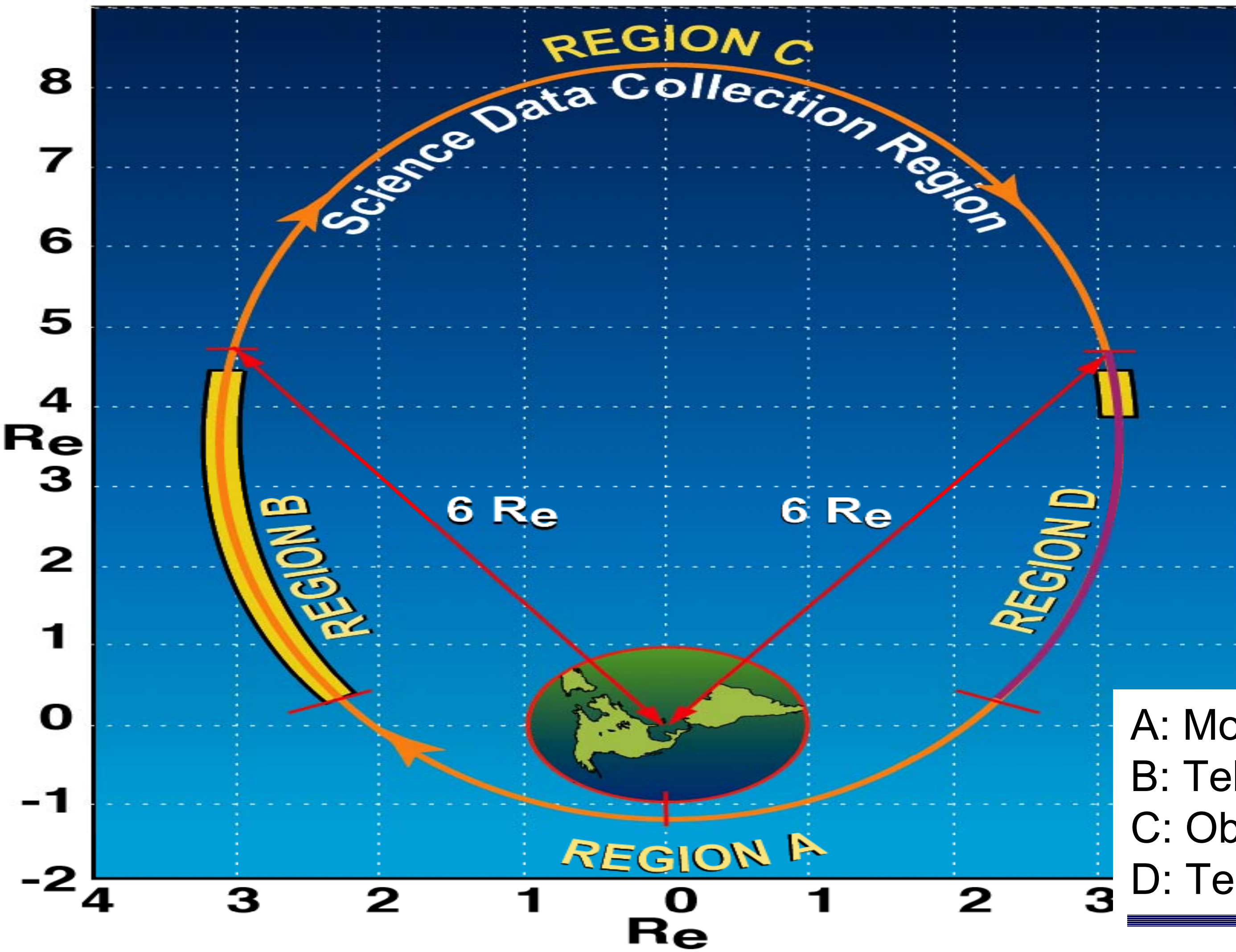


SPIDR Detector



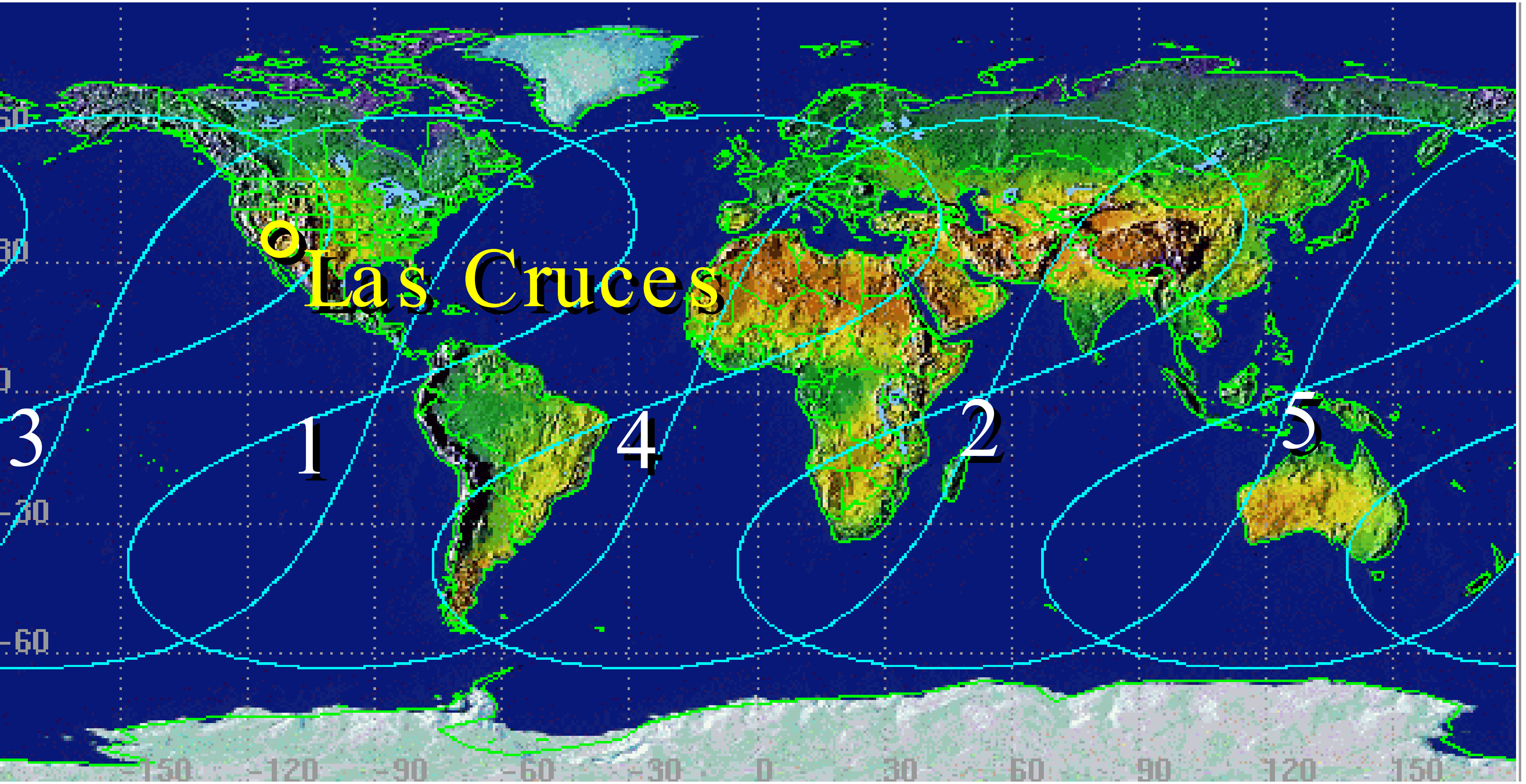


SPIDR Science Orbit

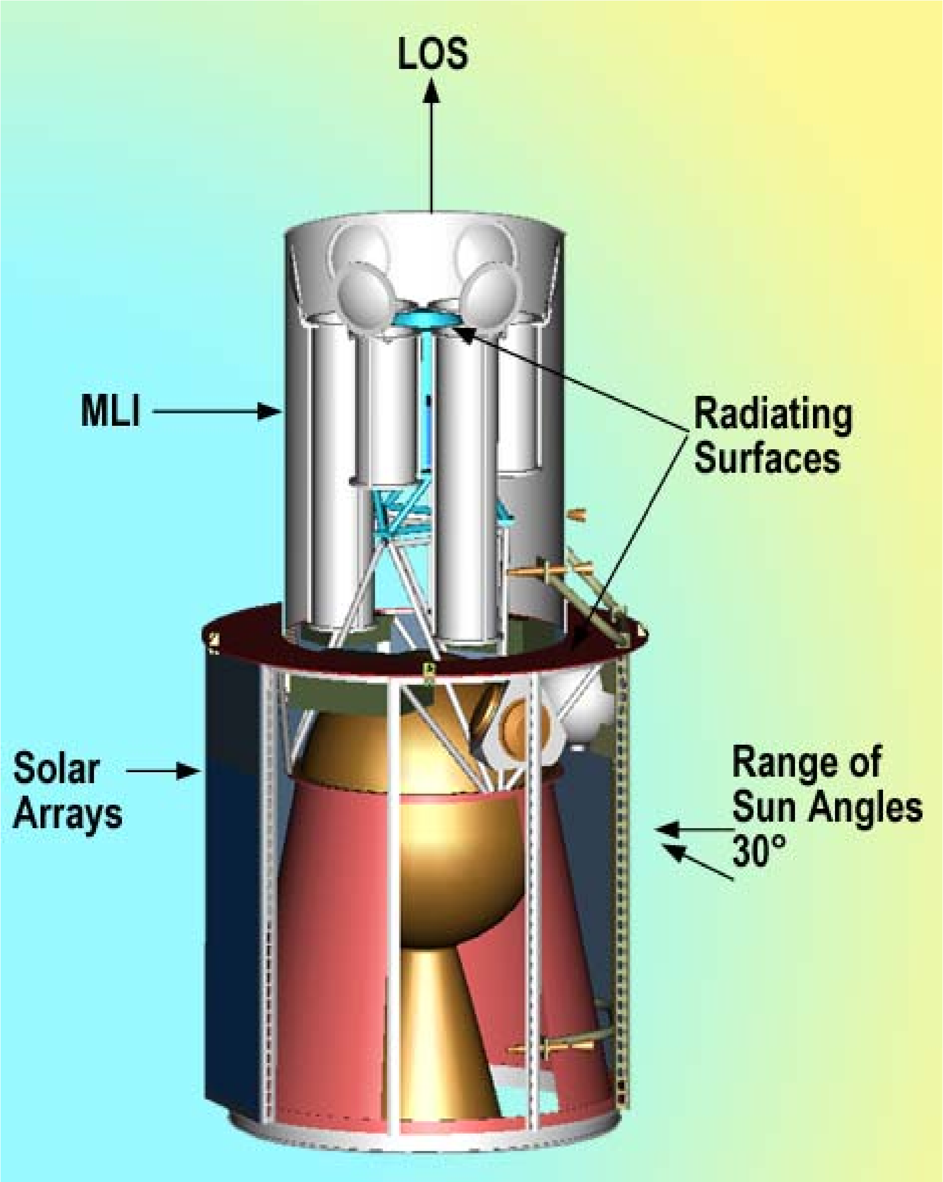


A: Momentum dumping
B: Telemetry, calibration
C: Observation
D: Telemetry, calibration

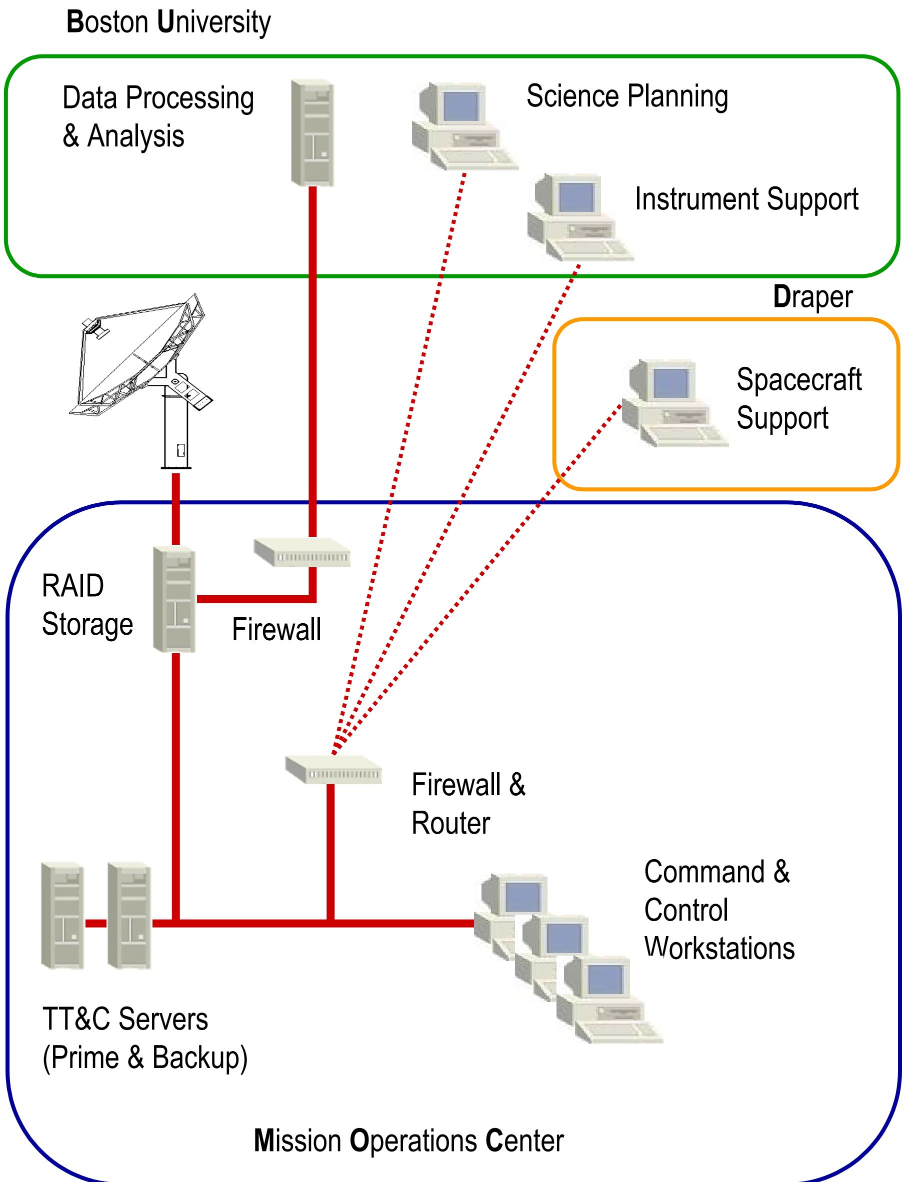
Repeat Ground Track



SPIDR Spacecraft



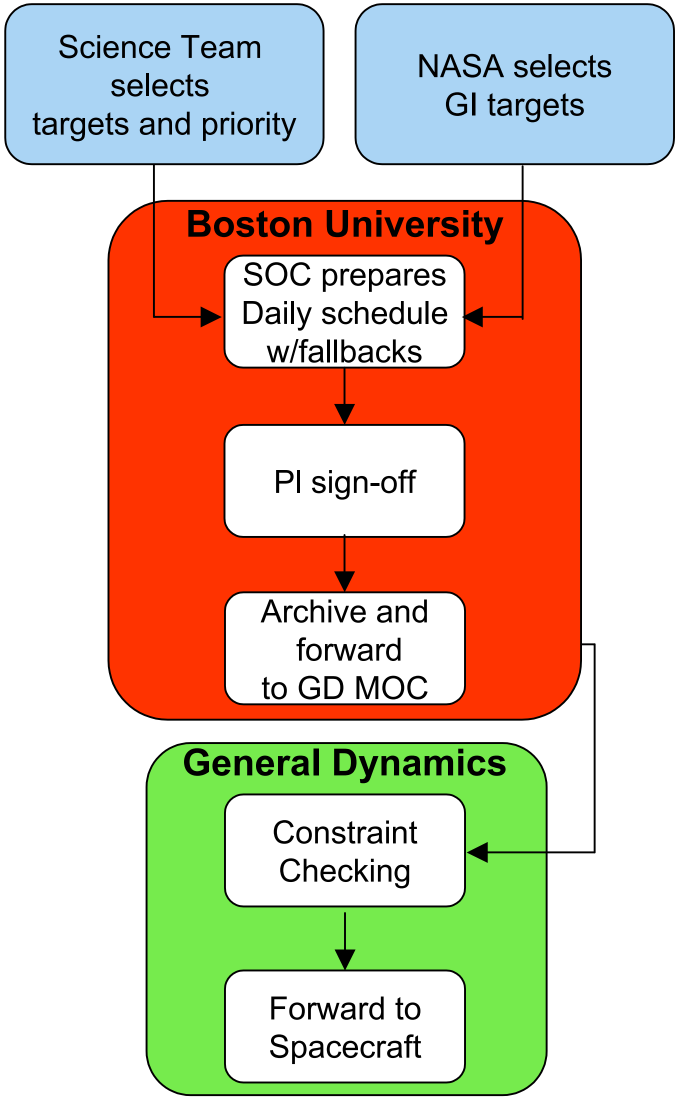
Mission Operations



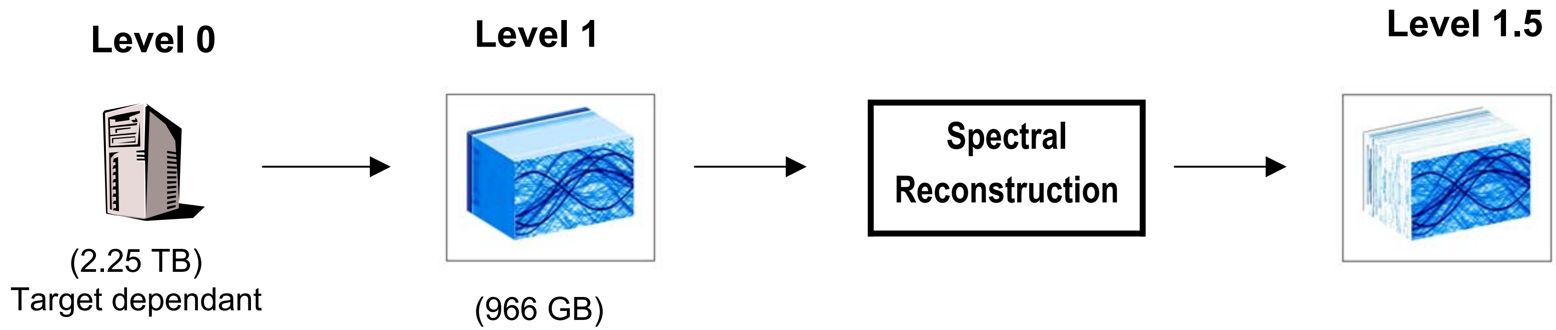
SPIDR Science Operations

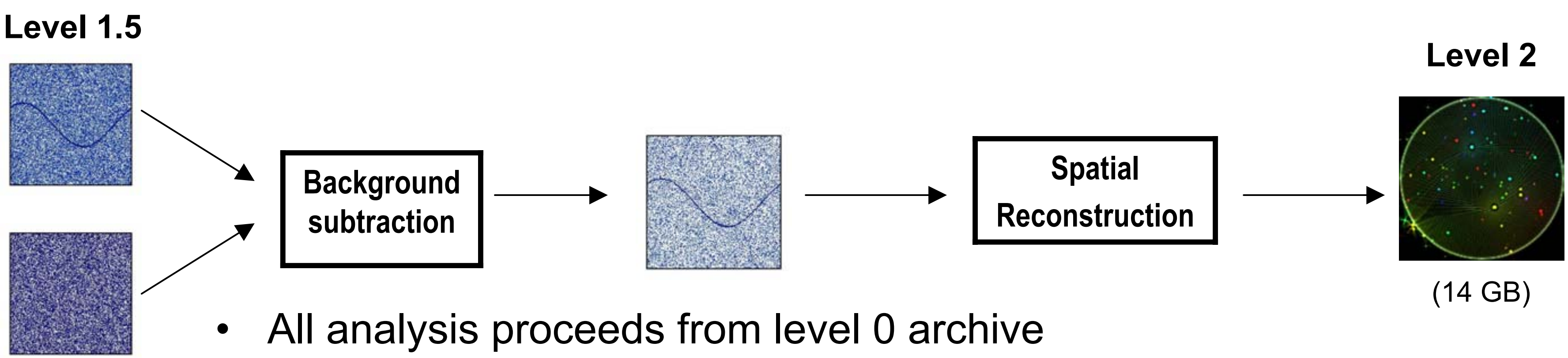
- **Simple operations scenario**
  - **Slow cadence – 1 observation per week**
  - **Single science mode**
  - **Single data path for all science and calibration data**
  - **Health and safety monitored by MOC**
  - **Data fidelity checked daily by BU**

- **Straightforward management**
  - **All mission operations and communications activities located at General Dynamics/Las Cruces**
  - **All science operations, archiving, calibration, and distribution located at BU**



Data Pipeline





- All analysis proceeds from level 0 archive
- All software, data and documentation publicly available
- All critical algorithms currently running
- Point source catalog generated from level 1 cubes (4.5MB)
- All software, documentation, level 0, level 1, and level 2 products will be provided to MAST

Summary

- SPIDR will be NASA’s next SMEX mission
- It is presently scheduled for launch in 2005
- We are excited and anxious to start